Architectural Composites

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General Notes:

FRP is a generic term for the composite of a polymer matrix reinforced with fibers. The fibers impart strength and stiffness to the composite and also act as crack stoppers. The matrix binds the fibers together, transferring loads from fiber to fiber. The matrix also protects the fibers from mechanical abrasion and chemical reactions with the environment. In principle, FRP material can be formed into any shape – it has no inherent form. In architectural applications of FRP the choice of manufacturing process is influenced by many factors including:

- Geometry
- Engineering requirements
- Shape repetition
- Shipping/transportation capabilities
- Installation equipment and capabilities
- Maximum unit size
- Surface finish

The most commonly used composition of fiber and matrix is glass fiber and polyester resin. These materials offer a good combination of strength, stiffness and economy. Carbon fiber with epoxy resin, can provide very high strength to weight but because of its cost is generally only used in very high performance applications. Vinyl ester resin can provide superior corrosion resistance, but usually far in excess of what is required for building cladding.

Mechanical Properties:

Actual properties of a composite vary with the types of reinforcements, matrices, cores, fillers, and so on. Some general guidelines assuming glass fiber and polyester resin are as follows:

- Density: 90 pcf
- Water Absorption: <0.1%
- Compressive strength: 23,000 to 29,000 psi
- Flexural strength (ultimate): 30,000 to 35,000 psi
- Modulus of elasticity: 2.4×10^{6} psi
- Tensile strength (ultimate): 25,000 to 39,000 psi
- Coefficient of thermal expansion: 11×10^{-6} in./in./deg F

Advantages/Disadvantages:

Advantages of FRP include:

- Lightweight – FRP is extremely light weight and can achieve similar structural performance to GFRC with less thickness.
- Flexibility – FRP is more resilient than GFRC and does not present the same brittleness and cracking issues.
- Customizable properties – Panel thickness, orientation of reinforcement, integral stiffeners, core material and thickness, etc is routinely engineered and customize to efficiently meet performance criteria.
- Durability and corrosion resistance – properly fabricated FRP does not rot like wood or rust like steel and has very good resistance to chemical corrosion.

Disadvantages of FRP include:

- Experience – Less experience with FRP as a façade material in the construction industry.
- Combustibility – FRP is less resistant to fire than, say, cement-based or metal alternatives, however recent technological advancements have overcome this as a barrier to its use as building cladding.
- Complexity – Properly choosing from among the thousands of combinations of fibers, matrices, additives, cores, etc, requires specialized fabrication and engineering knowledge.

Form and Finish:

The surface texture of a molded product is a direct reflection of the surface of the mould used to produce it. Further hand finishing can be done after molding. A surface coating can be incorporated in the molding processing using resin compatible with the matrix resin (this is termed a gel-coat). Polyester gel-coats are chosen for external exposure. They have good color fastness. Alternatively, an item can be painted post mold. Paints are typically polyurethane. It is possible to manufacture translucent FRP by using glass fiber reinforcement and an appropriate clear matrix polymer. Final finish surfaces can range widely from smooth and glossy to cratered and rock-like.

Some possible FRP finishes: glossy, polymer concrete, and translucent

Production:

Open Mold Process:

The process allows items to be produced with one molded surface. The largest items made using FRP are formed using open mould processes e.g. very large boat hulls which are formed with a male or female mold.

Hand layup of FRP on an open mold

A closed mold process requires a mold with matched male and female components. The process allows control of the finish of top and bottom surfaces. The size of items that can be produced using closed molds is limited and the mould cost is higher and as such this process tends only to be used for mass produced panels.

There are many variations on this process such as chopper gun application and vacuum infusion as well as a variety of other methods for producing FRP parts including pultrusion and filament winding. In most cases, open mold and hand layup make sense for large panels that require a molded surface on only one side.

Fire Performance:

From *American Composites Manufacturers Association: Guidelines and Recommended Practices for Fiberglass Reinforced Plastic Architectural Products*:

"The fiberglass portion of the FRP has minimal flammability and should be maximized in balance with the other performance requirements of the FRP. Glass contents will generally improve the fire performance of FRP systems and can range from 30% to 70% depending on the resin and additive characteristics as well as the fabrication process used."

With the proper fire retardant additives, FRP can easily be made to pass the ASTM E-84 Surface Burning Characteristics test with a Class 1 smoke development and flame spread. Recent advances allow the production of FRP cladding systems which also pass the NFPA 285 test which is a requirement under the 2009 International Building Code if such a product is to be used to any extent on the façade of a building over 40' high in the United States. Third party testing, and a listing and labeling program must be in place by the manufacturer to ensure compliance with building code requirements.

Durability:

Durability of FRP sculpture outdoors has as much to do with engineering and fabrication techniques as it does the materials themselves. Properly made and engineered FRP products will last for many decades. There is no evidence of long term deterioration on composite products that are subjected to appropriate allowable stresses.

Long-term durability is also related closely to moisture absorption. From *ACMA Guidelines*:

"The moisture absorption of FRP is negligible. Dimensional change and stresses due to moisture absorption are an insignificant design factor. Because of the low moisture absorption and high strain at failure, the freeze-thaw performance of FRP is excellent. Exterior parts should be provided with drainage to eliminate standing water and thus prevent ice damage. Cored laminates must be fabricated with no voids, and all openings cut through the finished laminate must be isolated from the core to ensure no water transmission or absorption by the core."

FRP is often chosen precisely because of its durability and resistance to corrosion and weathering. The earliest FRP boat hulls were being produced circa World War II. Many examples of FRP boats as old as 40 years are still sailing having undergone only superficial maintenance. One of the earliest uses of FRP was as "radomes" designed to protect microwave radar installations. While resisting the elements, they must also be thin enough – sometimes as little as 0.040" or less to prevent attenuation of the electromagnetic signals.

Radome in Liatarnet, Norway

Architectural examples illustrating durability include the Silver Legacy Dome in Reno, Nevada, constructed in 1995, and the retrofit to the domes of the St Joseph’s Cathedral in San Jose, California, constructed in 1986. Both of these projects are still standing in good repair, and have required little or no maintenance.

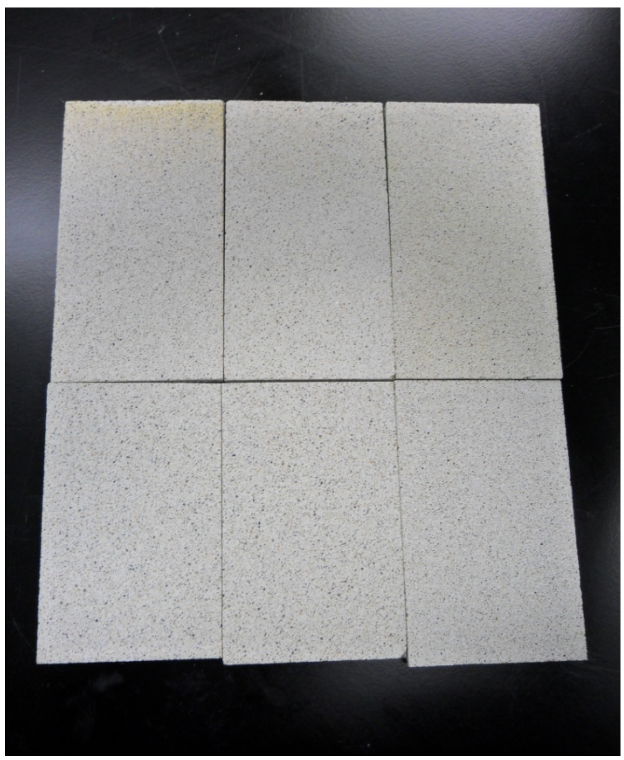
Left: St Joseph’s Cathedral, San Jose, CA; Right: Silver Legacy Dome, Reno, NV

Color Stability:

From *American Composites Manufacturers Association: Guidelines and Recommended Practices for Fiberglass Reinforced Plastic Architectural Products*:

"Weathering of FRP is related to degradation of the polymeric portion of the matrix by ultraviolet (UV) exposure. In some cases, UV exposure can cause embrittlement and micro cracking in an unprotected laminate surface. As with other building materials, the early stages of UV attack can cause color shift or yellowing and gloss changes. FRP should be protected from UV by an opaque gel coat surface or by painting the exposed surfaces. Incorporating UV screens into the matrix is also useful. Of these techniques, gel coating is the most common because it provides good surface finish and a deep 10 to 20 mil thick protective surface. Gel coating is used by the marine industry to provide a durable long life finish on boat hulls. Properly prepared FRP can also accept a wide variety of surface coatings, including oil- and water-based paint, as well as plural component systems such as urethanes. Factors influencing the weatherability of a gel coated surface include the type of gel coat resin, amount and type of fillers and colorants in the gel coat, and coating thickness."

With the proper use of additives and/or coatings, FRP performs well in accelerated aging tests at retaining gloss, color, and resisting yellowing.



Accelerated aging coupons of polyester polymer concrete test (control samples on bottom) – Kreysler & Associates Kastone finish at 2500 hours QUV exposure

Environmental Impact:

Understanding the actual environmental impact of any building system is complicated. One approach is to perform a Life Cycle Assessment (LCA) which accounts for the total impact of a specific material system in a specific application on a specific project, often in comparison to another possible material in the same application. Pound for pound, FRP generally requires more energy to produce than other products such as GFRC, however because of its high strength to weight, so little of it is normally used that its volumetric efficiency easily offsets the higher energy cost to produce it.

While it cannot simply be said that FRP shows better or worse environmental performance than another material, the LCA studies that are available analyzing its application on some specific projects almost universally indicate that it has much lower overall impact than alternatives.

Examples:

Due to building codes in the United States which are more stringent, particularly with respect to fire performance, there are limited domestic examples of large applications of FRP as a cladding material, however there are many examples world-wide and some smaller examples domestically. The expansion of the Museum of Modern Art in San Francisco, currently under construction will be the largest use of architectural FRP to date in the United States.

(Images under separate cover)

- Chanel Pavilion, Paris, 2008
  A mobile pavilion design by Zaha Hadid Architects, clad in 400 unique, complex curing FRP panels.
- One Ocean Pavilion, South Korea
  Designed by Austrian architects soma; one of the facades is comprised of tall, narrow, gill-like FRP panels supported at the top and bottom which can flex and open up the façade. This is an excellent use of FRP's lightweight and flexible properties.
- Carrasco Airport, Uruguay, 2009
  Raphael Viñoly; The roof of the main terminal is covered with FRP.
- Halley VI Research Station, Antarctica, 2012
  Designed for studying the earth's atmosphere and known for discovery of the ozone hole, this FRP-clad building withstands very harsh environmental conditions.
- Bing Concert Hall, Stanford, CA 2011
  Designed by Ennead Architects, these acoustic panels are designed and engineered to reflect sound in a specific manner. FRP is ideal for capturing the complex curvature and articulation of the ceiling and walls.
- California Bay House, 2007
  The main living space of this house is constructed as a 2-story "monocoque" shell with a 1.5" thick blasa core FRP sandwich. The shell itself provides the primary structure without the support of additional columns or bracing.
- San Francisco Museum of Modern Art expansion project, 2015
  The entire east façade of this 11 story building in downtown San Francisco is to be clad with an FRP rainscreen.